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AFWAL-TR-83-4033
Volume VI

ICAM MANUFACTURING COST/DESIGN GUIDE

Volume VI - Project Summary

BATTELLE COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201-2693

JANUARY 1985

FINAL REPORT FOR PERIOD 1 OCTOBER 1979 - 31 AUGUST 1984

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Industry's growing need for aerospace systems with improved performance at reduced cost demands an emphasis on design to lowest cost. The ICAM "Manufacturing Cost/Design Guides" (MC/DG), developed for airframes and electronics, assist designers by identifying and documenting cost drivers and cost reduction methods. Designers can use the formats in the Guides for trade-off studies of airframe performance, reliability of electronics, and manufacturing cost. These formats provide the costs of procured items, material removal, detail fabtication, assembly, material treatment, and test, inspection, and evaluation. Industry has found numerous applications for the MC/DGs, resulting in significant cost savings.

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FOREWORD

This "Manufacturing Cost/Design Guide" (MC/DG) document summarizes the work performed, overall results, conclusions, and cost savings, for Air Force Contract F33615-79-C-5102 conducted from 1 October 1979 through 31 January 1985. The contract was sponsored by the Computer Integrated Manufacturing Branch, Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories. At the conclusion of this program, the Air Force CIM Project Manager was Lt. Kenneth A. Lillie. Capt. Richard R. Preston was the Project Manager until 15 September 1984. In previous phases, the following Air Force personnel directed the program; Mr. John R. Williamson, Capt. Dan. L. Shunk, and Capt. Steven R. LeClair.

The organization of the program is comprised of a coalition of seven participating companies with Battelle's Columbus Laboratories (BCL) as the prime contractor. Mr. Bryan R. Noton was the Program Manager for the MC/DG contract. The supporting companies are listed below:

Airframe Company Subcontractors	Company Project Managers
General Dynamics Corporation, Forth Worth Division	Phillip M. Bunting
Grumman Aerospace Corporation	Vincent T. Padden Anthony J. Tornabe
Honeywell, Incorporated	Robert R. Remski
Lockheed-California Company	Anthony J. Pillera John F. Workman
Metcut Research Associates, Incorporated	Robert L. Carlton
Northrop Corporation, Aircraft Group	John R. Hendel Al P. Langlois
Rockwell International Corporation, North American Aircraft Operations	Ralph A. Anderson
Rockwell International Corporation, Avionics & Missiles Group, Collins Avionics Division	John G. Vecellio

Mr. L. I. McDonald, formerly, Manager, Advanced Manufacturing Plans, Vought Corporation, served as a consultant.

Note that the number and date in the upper right corner of each page of this document indicate that the document has been prepared according to ICAM's Configuration Management Life-Cycle Documentation requirements for Configuration Items (CIs).

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INTRODUCTION

1.1 Background

Early Air Force manufacturing cost reduction studies concluded that aerospace designers do not have adequate cost information on a broad range of trade-offs between performance and manufacturing cost. An Airframe Panel, for which Mr. John Williamson was the representative for the Materials Laboratory, AFWAL, recognized that the lack of information resulted in high materials, manufacturing, and inspection costs. Specifically, this Panel identified a need to:

- Systematically address manufacturing and design cost drivers
- Quantify these cost drivers in man-hours or dollars
- Improve design/manufacturing interaction to deal effectively with multi-disciplinary problems
- Achieve the required interaction through a cost-design manual that presents cost driving manufacturing operations to designers.

Of 1,892 chief engineers later completing a survey conducted by Machine Design on "New Design/Redesign", 91 percent cited lower engineering/manufacturing costs as their most frequently encountered problem. The problem of product legislative requirements was cited by 58 percent, material/component availability by 53 percent, and lower product operating costs by 23 percent.

The conclusion is that all products and industries need to reduce acquisition, operations, and maintenance costs of engineering products and systems. The results of the program discussed here are, therefore, important for most manufacturing industries in the United States.

At present, it is difficult for the aerospace industry to recruit qualified design engineers to address these problems. Because of this and other factors, university and college graduates will have to play an increasingly important role in minimizing cost in the aerospace industry.

In the aerospace system manufacturing environment, which

- Depends heavily on manpower
- Is cyclic
- Has little automation
- Has few customers and excessive capacity
- Requires highly skilled personnel
- Is high technology oriented
- Is driven by product excellence;

this need to reduce cost is critical. The "Manufacturing Cost/Design Guides" (MC/DGs) for airframes and electronics were developed to respond to this need.

The individual designer seldom has the training and sometimes does not have the experience to conduct structural performance/manufacturing cost trade-off studies during his daily efforts. However, today, designers are rated not only on their ingenuity in meeting weight and cost objectives, but also on their ability to achieve this within design schedule limitations (Figure 1). Design-to-lowest cost is now a design discipline. However, as shown in Tables 1 and 2, there are significant differences in design features and technology requirements between aircraft types and, hence, the cost-effectiveness criteria influencing objectives for cost savings. Thus design teams must be provided with:

- Tools
  - Identification and documentation of cost drivers and cost reduction methods in airframe design and manufacture
- Incentives
  - Cost targets against which performance of design personnel can be measured.

In the past, the designer had only one resource to determine cost: the cost estimator. The cost estimator is still an important factor in the final iteration of the design prior to production commitment. However, it is often difficult to meet scheduling requirements, while considering an adequate number of design alternatives and ascertaining, with confidence, that the selected design is actually the lowest cost alternative.

1.2 Cost Drivers

The following list provides an overview of cost drivers in the manufacture of discrete parts of Air Force systems from the viewpoint of the entire industry:

- Cost drivers common to all industry are energy, materials, and equipment.
- Common cost drivers are found throughout all subsystems.
- Cost drivers common to the aerospace industry are metal removal, high part count, and material utilization.
- Cost drivers with the highest impact are found in airframe manufacture.

PRESENT AIRCRAFT DESIGN TEAM PRIORITIES

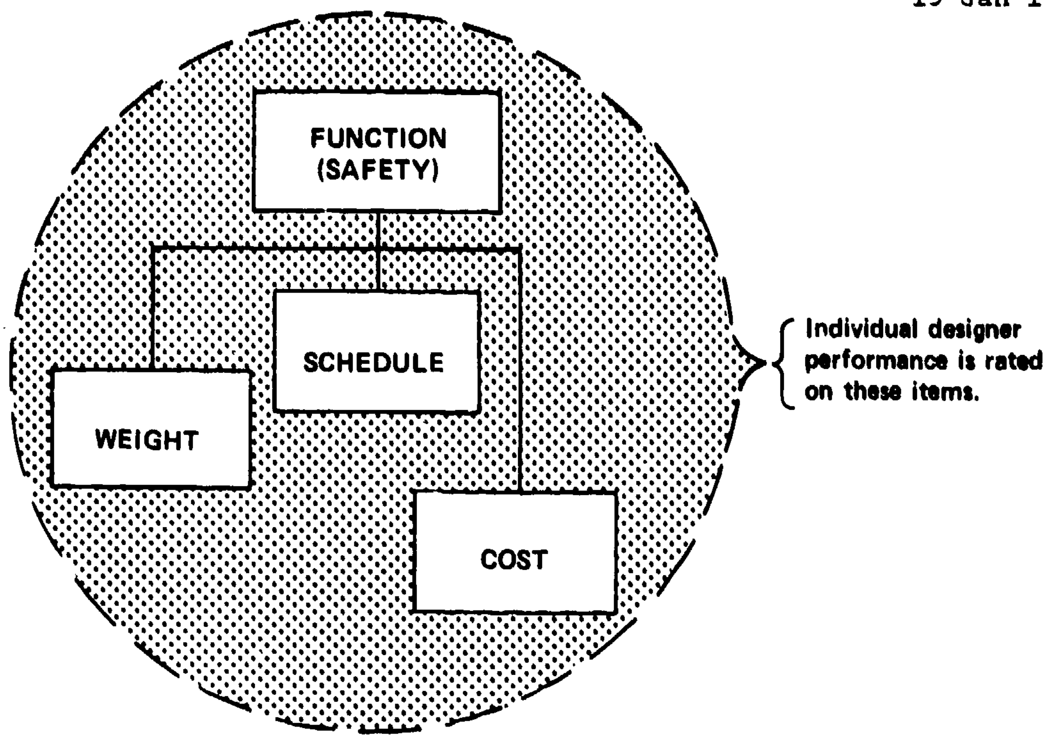


FIGURE 1. PRESENT AIRCRAFT DESIGN TEAM PRIORITIES

MC/DG IMPACT ON ICAM THRUST AREAS

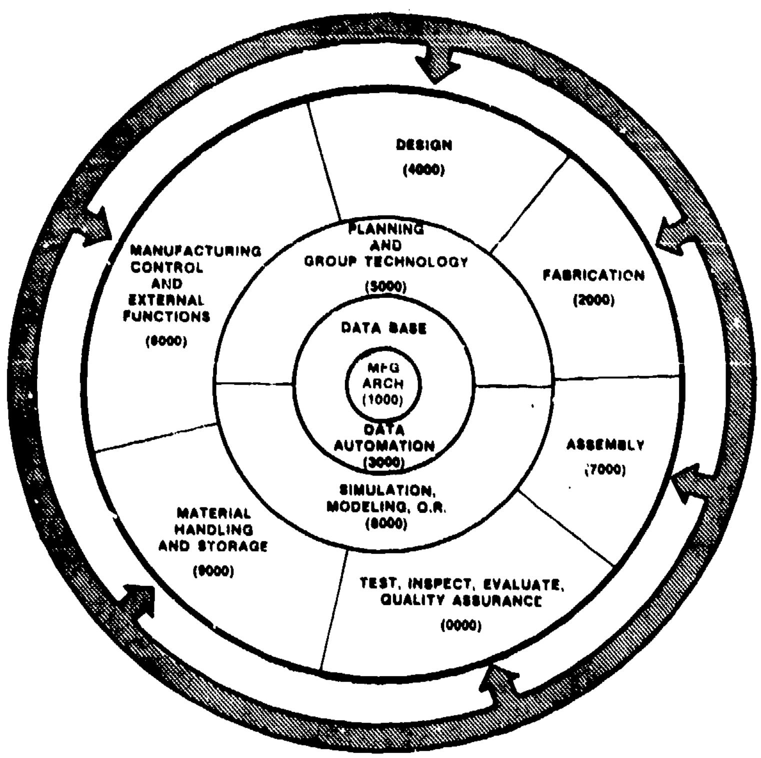


FIGURE 2. THE MC/DG IMPACTS ALL ICAM THRUST AREAS

TABLE 1.

**LOW SPEED AIRCRAFT DESIGN FEATURES
VERSUS
MANUFACTURING TECHNOLOGY REQUIREMENTS**

	DESIGN FEATURES	MT REQUIREMENTS
SUBSYSTEMS COMPONENTS	• USE EXISTING ENGINE – AVIONICS – ACCESSORIES, ETC.	• MINIMUM – METHODS IMPROVEMENTS ONLY
STRUCTURE	• PRIMARILY S/M – MINIMUM MACHINED PARTS • CONSTANT SECTION FUSELAGE • CONSTANT SECTION CONTROL SURFACES • USE LH/RH INTERCHANGEABLE COMPONENTS (LANDING GEAR, CONTROL SURFACES)	• MINIMUM – LOW COST S/M TOOLING • COMMON USE TOOLING • MINIMUM EQUIPMENT REQUIREMENTS
ASSEMBLY AND INSTALLATION	• CONVENTIONAL ALUMINUM FASTENERS • LAP SKIN – JOINTS • LOW PRESSURE HYDRAULIC SYSTEMS • DESIGNED FOR BREAK-BACK SUBASSEMBLIES	• PERMITS MAXIMUM USE OF AUTOMATIC RIVETING: • M.T. IS AVAILABLE, PROVEN, AND ONLY REQUIRES CONTINUED MANUFACTURING-TO-COST IMPROVEMENTS

TABLE 2.

**HIGH SPEED AIRCRAFT DESIGN FEATURES
VERSUS
MANUFACTURING TECHNOLOGY REQUIREMENTS**

	DESIGN FEATURES	MT REQUIREMENTS
SUBSYSTEMS	• ENGINE IN DEVELOPMENT PARALLEL WITH AIRFRAME – ADVANCED AVIONICS-HIGH PERFORMANCE ACCESSORIES	• NEW MT REQUIREMENTS – NEW TOOLING – EQUIPMENT INVESTMENTS • CONTINUED MT – MTC
STRUCTURE	• EXTENSIVE USE OF EXOTIC METALS • DOUBLE CURVATURE FUSELAGE • EXTENSIVE S/M AND MACHINE PROFILING • TAPERED WINGS, CONTROL SURFACES • COMPOSITES	• NEW MT FOR MACHINING EXOTIC METALS • EXPENSIVE MACHINE TOOLS • CAM REQUIREMENTS • NEW MT FOR COMPOSITE MANUFACTURE • CONTINUED MT – MTC
ASSEMBLY AND INSTALLATION	• EB WELDING • SPECIAL PURPOSE FASTENERS • BUTT JOINTS – FAYING SURFACES • PRESSURE SEALING • HIGH PRESSURE HYDRAULIC SYSTEMS • HIGH DENSITY WIRING/TUBING • WIRE SHIELDING	• LIMITED USE OF AUTOMATIC RIVETING • MT FOR EB WELDING • HIGH MAN-HOURS FOR CLOSE TOLERANCE ASSEMBLY • MT FOR DEVELOPMENT OF HIGH PRESSURE HYDRAULIC FITTINGS AND TUBING • AVOID RF PROBLEMS

- Engines, mechanical systems, and crew systems have a common set of cost drivers that include metal removal, heat treatment, inspection, and specifications.
- Schedule limitations frequently make it difficult for designers to adequately address cost drivers and, therefore, cost data must be presented in a way that will not significantly affect schedules.

Cost drivers can be related to various categories of aircraft system development:

- Performance
- Design
- Material selection
- Manufacturing.

As an example, the cost drivers for auxiliary components are:

- Performance related
  - Reduced weight
  - Higher operating speeds
  - Increased reliability and maintainability
- Design related
  - High part count
  - Nonstandardization
  - Tight tolerances
- Material related
  - Cost
  - Availability
  - Utilization
  - Energy
  - Inventory
- Manufacturing related
  - Inspection
  - Equipment
  - Cyclic production
  - Small lot sizes
  - Job shop environment
  - Highly skilled labor

- Metal removal
- High scrap rate
- Deburring/hand-finishing
- Heat treatment
- Hand fit-up
- Energy (e.g. curing).

Cost drivers sometimes initially result from the required progress in technology. For example, aircraft structural concepts utilizing advanced composites or superplastic-formed/diffusion-bonded (SPF/DB) titanium require new developments in manufacturing technology to enable the cost benefits of these technologies to be fully realized. These developments in manufacturing technology are necessary if the requirements for increased performance are to be met, while, at the same time, remaining competitive. To alleviate this problem, the most promising avenue of development is manufacturing sophistication, e.g., computer-aided manufacturing (CAM), robotics, and adaptive process control.

Because of the complex nature of the objectives of designing and manufacturing aircraft systems to the lowest possible cost, manufacturers are turning increasingly to the use of the digital computer for both the design and manufacture of aircraft. The computer-aided concept is the basis of the Air Force's Integrated Computer-Aided Manufacturing program, known as ICAM. ICAM will help industry to revolutionize its approach to improving overall productivity, at all levels of the manufacturing hierarchy, from shop floor operations to executive decision making. The ICAM thrust areas are shown in Figure 2.

The MC/DG is a critical part of the ICAM program. The MC/DG, at this time, covers design, fabrication, assembly, and test, inspection and evaluation (TI&E).

The MC/DG sections developed were prioritized by the Air Force and industry based on aerospace cost reduction needs. However, the "Manufacturing Cost/Design Guide" (MC/DG) study was also initiated to further aid in attaining the objectives of the Integrated Computer-Aided Manufacturing (ICAM) program, which are:

1) Reduce aerospace systems cost
2) Provide leadership to industry
3) Increase competence in aerospace manufacturing
4) Provide for ICAM technology transfer
5) Improve the USAF's mobilization position
6) Demonstrate the capability for a totally integrated manufacturing system.

1.3 Scope

With its step-by-step approach to attaining optimum performance at minimum cost, the "Manufacturing Cost/Design Guide" (MC/DG) is developed expressly for designers. It presents easy-to-use formats that provide designers with manufacturing cost data developed from industry-wide practice. It allows the user (design, manufacturing, and procurement personnel) to quickly make the trade-offs necessary to achieve, with confidence, lowest acquisition cost. During the design phase, designers with different levels of experience can conduct simple trade-offs between manufacturing processes for metallic and composite airframe components and assemblies and also electronics. The MC/DG also establishes data at a level that complements and is conducive to computer-aided design and manufacturing systems.

The MC/DG was developed by establishing a model for its contents. Manufacturing cost drivers and data requirements were identified. Designer-oriented formats meeting specified criteria for conventional and emerging technologies were recommended. Based on this model, three MC/DG sections were developed to determine the effectiveness of the overall concepts. These concepts, focusing on sheet metal aerospace discrete parts and first-level mechanically fastened assemblies, were demonstrated and proven. The applicability of the concept to the fabrication of composites was also studied, and, while a broad data development effort was not initiated, the concept was again demonstrated and proven. However, limited data have been developed for composites. Designers from major aerospace companies used the data and formats to conduct trade-off studies of structural performance and manufacturing cost of fuselage panels in aluminum, titanium, and composites. The results provided significant measurable benefits and justified continued expansion of the guide to include sections on forgings, castings, extrusions, machining (metals), and test, inspection, and evaluation (TI&E) of sheet metal, composites, castings, machining (metals), and assembly. The MC/DG includes formats providing manufacturing cost data and detailed instructions for their use.

Table 3 lists the functional data sections of the "MC/DG for Airframes" and Table 4, the sections of the "MC/DG for Electronics."

The selection criteria for determining the manufacturing technologies for initial study were:

- Provides significant and early payoff for USAF weapon systems
- Reflects findings from earlier AFWAL/ML studies (References 1 and 2)
- Coordinates with ICAM/CIM and IPAD programs
- Assures easy development of computerized MC/DG
- Is broadly applicable to entire industry

TABLE 3.

MC/DG FUNCTIONAL CONTENTS: MANUFACTURING TECHNOLOGIES FOR AIRFRAMES

NOTE:
COMPLETED SECTIONS *PLANNED PROGRAM*

I	II	III	IV	V	VI
PROCURED ITEM COSTS	MATERIAL REMOVAL COSTS	DETAIL FABRICATION COSTS	MATERIAL TREATMENT COSTS	ASSEMBLY COSTS	TEST, INSPECTION AND EVALUATION COSTS
EXTRUSIONS	MACHINING	SHEET METAL	HEAT TREATMENT	*MAJOR AND FINAL ASSEMBLY FOR:*	SHEET METAL
CASTINGS		*COMPOSITES-EXPANSION*	SURFACE TREATMENT	*METALLICS (MECHANICAL) NONMETALLICS (INCL. COCURING)*	ASSEMBLY
FORGINGS		*SUPERPLASTIC FORMING*		*ADHESIVE BONDING*	CASTINGS
				DIFFUSION BONDING	FORGINGS
				WELDING	MACHINING
				WELD-BONDING	COMPOSITES

CATEGORIES = PROCURED ITEM COSTS, ETC.
SECTIONS = FORGINGS, ETC.

TABLE 4.

MC/DG FUNCTIONAL CONTENTS: MANUFACTURING TECHNOLOGIES FOR ELECTRONICS

I	II	III		IV
PROCURED ITEMS	DETAIL FABRICATION	ASSEMBLY		TEST, INSPECTION, AND EVALUATION (TI&E)
SCHEMATIC PARTS	METALLICS	MECHANICAL ASSEMBLY	HYBRIDS	CARD/MODULE LEVEL TEST
INTERCONNECT PARTS	NON-METALLICS	COMPONENT ASSEMBLY (PRE-WAVE AND POST-WAVE)	CHASSIS ASSEMBLY	BURN-IN/SCREENING TEST
HARDWARE	SURFACE TREATMENT	CLEANING	FINAL EQUIPMENT ASSEMBLY	DEVICE/EQUIPMENT TEST
FABRICATED PARTS	COATINGS	SOLDERING	POST-ASSEMBLY PROCESSES	
	MARKING	SHEET METAL/ STANDOFF ASSEMBLY (HARD WIRING)	POTTING	
		CABLE/WIRE HARNESSS ASSEMBLY	ADHESIVES	

TABLE 5.

MC/DG COST WORKSHEET

PAGE ____ ____

DESIGN CONCEPT		RECURRING COST (RC)										NONRECURRING COST (NRC)				PROGRAM COST		
		(L . LC + TI&E) LR = L$ + M$ = RC . P/AC . DQ = PRC										(NRC + TI&E) LR = PNRC				10 + 14 DQ = COST/AC		
PART NO.	DESCRIPTION	LABOR MC/DG MH/PT (1)	LC FACTOR (2)	LABOR TI&E MH/PT (3)	LABOR RATE $/MH (4)	LABOR RC $/PT (5)	MAT'L $/PT (6)	REC. COST/ PT. $ (7)	PARTS PER AC (8)	DES. QTY. (9)	PROG. RC $ (10)	NRC MC/DG MH (11)	NRC TI&E MH (12)	LABOR RATE $/MH (13)	PROG. NRC $ (14)	PROG. COST $ (15)	DES. QTY. (16)	COST/ AC $ (17)
	TOTALS																	

REMARKS ______________________________

BY: ______________

DATE: ______________

- Includes manufacturing processes that impact airframe cost and, hence, alleviate cost drivers
- Identifies and maximizes number of cost drivers favorably impacted
- Effectively demonstrates MC/DG methodologies
- Offers data that can be easily verified and revised
- Does not cause adverse reactions from cost-estimating and general management.

The MC/DG identifies the cost drivers the designer can control. Performance can be traded back once the design requirements of the system have been met or exceeded, for example, with a low-speed aircraft. The MC/DG also provides information to promote interaction between manufacturing and design, for example, alternative facilities due to shop loading requirements. While the designer is principally interested in the lowest cost process for the manufacture of airframes, avionics, or other subsystem discrete parts, when communicating with manufacturing, the principal discussions may revolve around the alternative methods to produce a certain part.

The MC/DG can be used at all levels of the design process, but the preliminary design phase, the "window of opportunity," is particularly important. Figure 3 illustrates how the leverage for cost savings decreases as the program progresses through production. The preliminary design phase is industry's opportunity to achieve the lowest cost design. It is here that radically innovative approaches to structural design concepts and manufacturing technology choices can significantly impact cost. Configuration selection normally offers the major opportunity to reduce cost. As Figure 3 indicates, at this preliminary design phase, only a few percent of the program costs have been expended, yet decisions have been made that influence 90 to 95 percent of the total cost, including operations and maintenance costs. As the program progresses through detail design and production, it is extremely difficult to reduce the cost by more than a few percent, even with innovative approaches to design and manufacturing. As soon as the detail design phase is approached, the majority of components considered for redesign to utilize alternative advanced manufacturing processes or materials must meet form, fit, and function requirements of the part or assembly being considered for replacement. Figures 4 and 5 show the cost impact of decisions as a function of the number of decisions. The major milestones are indicated throughout the development of an aircraft system committed to production.

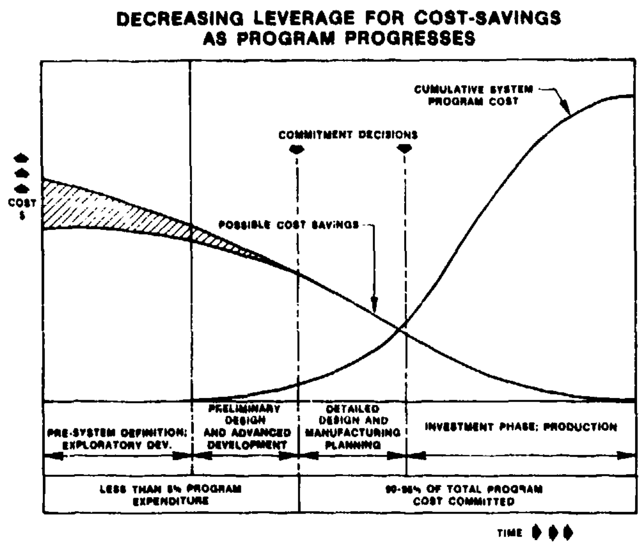


FIGURE 3. DECREASING LEVERAGE FOR COST SAVINGS AS PROGRAMS PROGRESS

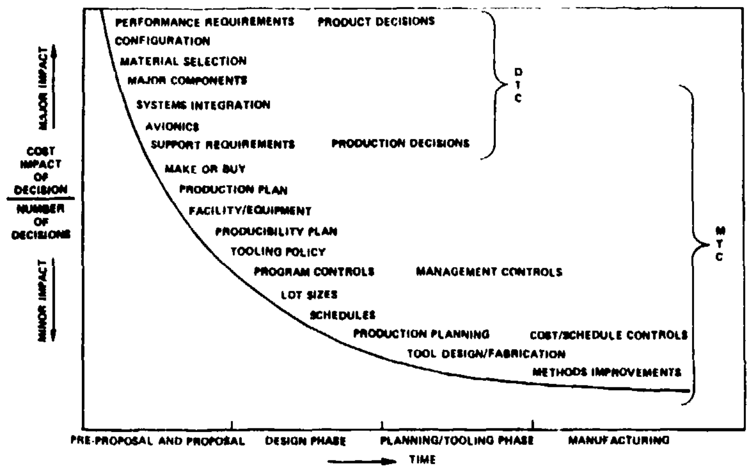


FIGURE 4. AEROSPACE VEHICLE DESIGN DECISIONS AND THEIR COST IMPACT

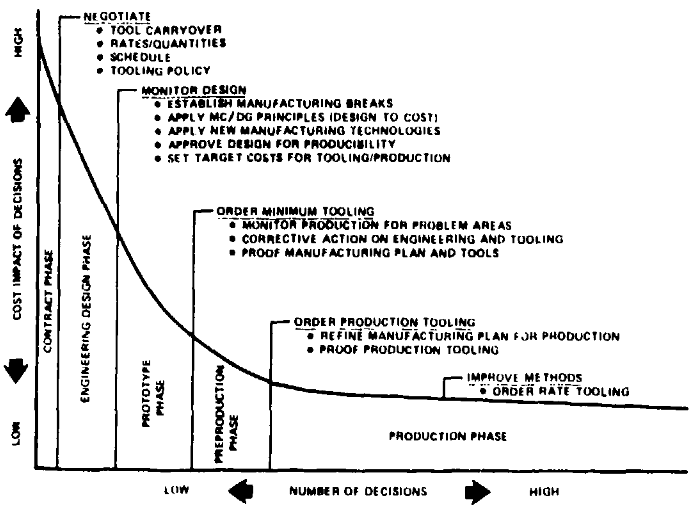


FIGURE 5. MANUFACTURING DECISIONS AND THEIR COST IMPACT

SECTION 2.0
OBJECTIVES

The MC/DGs achieve cost-effective, cost-competitive airframe and electronic designs through an innovative approach that provides designers with:

- Cost flexibility; readily adaptable during development of airframe or electronic systems
- Unique building-block methodologies
- Capability to complete, within schedule limitations, trade-off studies for many alternative design configurations, using different manufacturing technologies.

The specific objectives of the MC/DG are to:

- Provide simple, relative, and quantitative cost comparisons of manufacturing processes
- Orient formats and man-hour data for use in all design phases
- Emphasize potential cost advantages of emerging technologies
- Identify cost driving manufacturing operations as targets of computer integrated manufacturing (CIM) thrusts
- Allow designers to conduct more performance/manufacturing cost trade-offs than previously possible
- Put designers on the lowest cost track early in the design process.

Furthermore, the MC/DG data and formats have been developed for ease of computerization (Reference 6).

To achieve the above objectives, a Battelle Memorial Institute-industry coalition was organized. Thus, the MC/DG's were developed by a team of major aerospace companies represented by experts in design, cost estimating, and manufacturing. This approach brought to the development effort:

- Industry-wide data on a cross-section of small and large aircraft, both military and commercial
- A base for deriving average industry data

- An interface with all levels of designers, encouraging early technology transfer to industry
- Each company's varied expertise, which makes results more viable
- A basis for ground rules and methodologies to develop manufacturing man-hour data and designer-oriented formats
- Greater confidence in verifying data and formats for designer use
- A broad base for utilizing emerging technologies and Air Force manufacturing technology program results.

The data requirements and MC/DG formats were reviewed at team member companies by persons representing:

- Management
- Engineering (design and support)
- Manufacturing (fabrication, tooling, and quality control)
- Procurement (materials, parts, and equipment).

Management involvement accelerated technology transfer of the program results through early use of the MC/DGs.

At each company, six to ten persons were involved in developing data and in testing and evaluating the final averaged data to be presented in the manufacturing technology functional sections of the MC/DG. At the proposal stages, each company agreed to provide highly experienced staff from the different disciplines required to develop documents that would be approved by management and subsequently accepted, enthusiastically, by designers. This not only minimized design and manufacturing costs, but also substantially improved design/manufacturing interaction. The companies provided highly qualified persons, several with 30 to 40 years of experience.

Three constracts have been awarded in the development of the MC/DG. The principal objectives of the first, a 1-year program (Contract No. F33615-75-C-5194; Reference 4), were to:

- Identify the Data Requirements for the MC/DG for both conventional and emerging manufacturing technologies

- Identify the Basic Format Design Criteria and Create formats displaying cost driver effects (CDE) and cost-estimating data (CED) for each section or manufacturing technology in the MC/DG

- Prepare a Detailed Model of the MC/DG for industry examination. The model consisted of a section-by-section layout of all sections, including sample data sheets and formats for each conventional and emerging manufacturing technology

- Prepare an Implementation Plan for the MC/DG, i.e., define the mechanisms to develop and/or collect CDE and CED data for insertion in the designer-oriented formats.

The objectives of the second contract, a 15-month program, (Contract No. F33615-77-C-5027; Reference 6), were to implement the following Demonstration Sections of the MC/DG:

- Sheet-Metal Aerospace Discrete Parts

- First-Level Mechanically Fastened Assemblies

- Advanced Composites Fabrication.

A further objective of this program was to utilize the data developed and the designer-oriented formats for actual trade-off studies on three types of fuselage shear panels, i.e., aluminum, titanium and carbon/epoxy.

The third program (Contract No. F33615-79-C-5102) required the development of MC/DG sections for:

- Castings
- Forgings
- Extrusions
- Test, inspection, and evaluation (TI&E)

Furthermore, as castings, forgings, and extrusions are normally machined prior to assembly in aerospace structures, data and formats were developed for the machining of typical discrete parts manufactured utilizing these methods. TI&E was included in the MC/DG, because, in the case of certain materials, such as graphite/epoxy, and manufacturing methods, such as casting, it can be a cost driver that needs to be included in trade-off studies comparing various manufacturing methods.

The third program also required the development of an MC/DG for electronics fabrication, assembly, and TI&E. A series of typical discrete parts such as transistors, capacitors, diodes, and hybrids, were analyzed, as were, typical assemblies, such as printed wiring boards. Hand, semiautomatic, and automatic soldering and insertion processes were also analyzed. Furthermore, the manufacturing costs to meet typical reliability requirements in electronics were developed for the selected discrete parts.

The fourth program required the development of a functional section of the MC/DG for machining of metals. The MC/DG for machining contains CDE formats for part size, material types/removal rates, tolerances, surface finish, and hog-outs. The CED formats are presented in three groups showing machining features of frames, wing skins, spars, ribs, stiffeners, and longerons; machining features of pins, bolts, bushings, inserts, sleeves, etc.; and also general machining features applicable to most machined airframe parts.

The third and fourth programs are reported in References 6 and 7.

SECTION 3.0
FORMAT DEVELOPMENT

3.1 Data Presentation

Two methods of data presentation are used to simplify designer use of manufacturing cost data and provide direction toward the lowest cost designs. Both use simplified formats from which designers can quickly extract and use the necessary data.

The cost driver effects (CDE) approach gives designers qualitative cost guidance for use in various trade-off studies. CDE guidance is particularly important in conceptual and preliminary design. Using these data to compare different configurations, designers obtain lowest cost designs while meeting performance, reliability, and other design requirements.

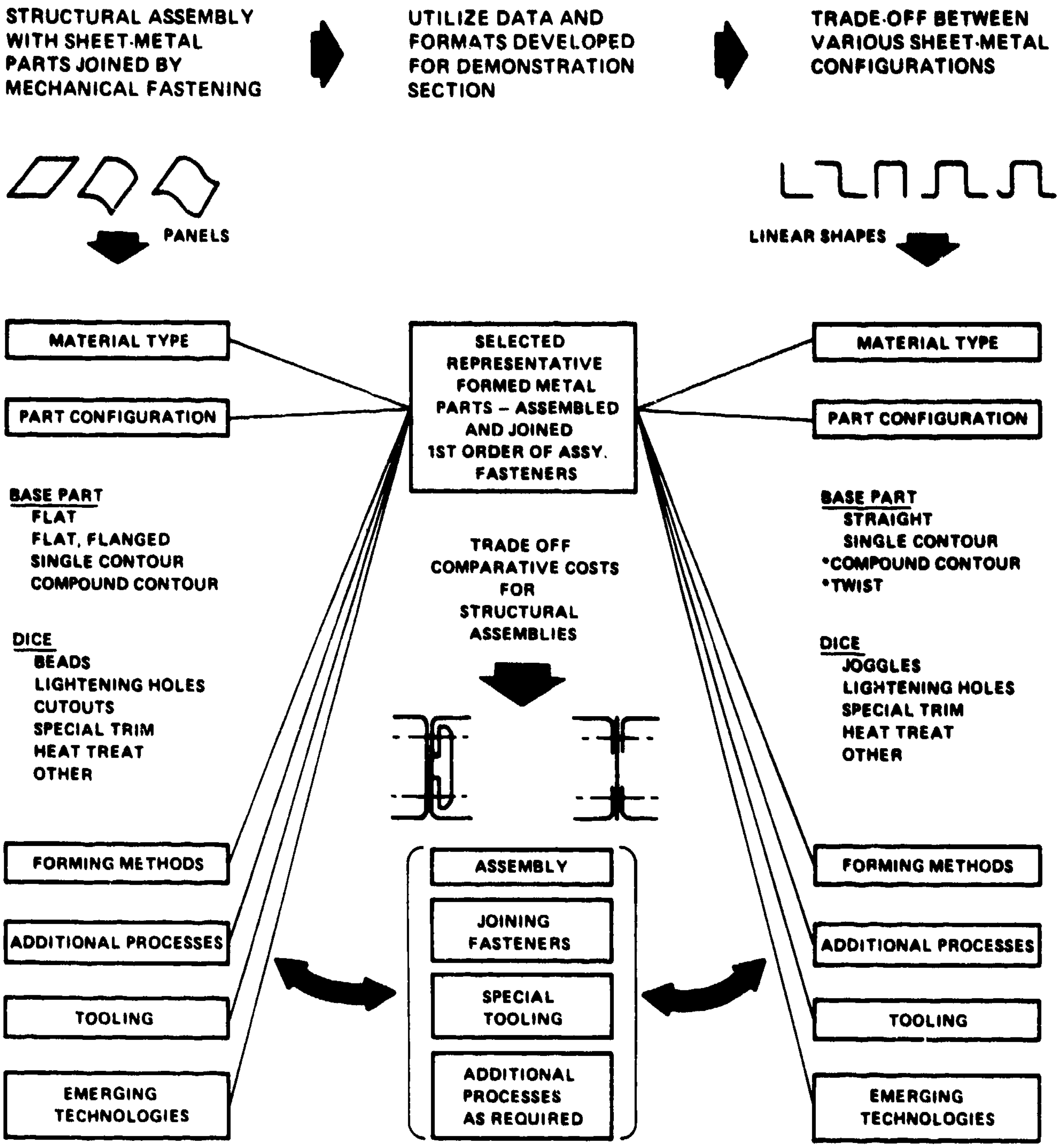
The cost estimating data (CED) approach provides quantitative data that designers use to estimate fabrication costs for a candidate design configuration. These man-hour or cost data are used in the trade-off studies.

The objectives of the CDE and CED methodologies are to provide:

• A simple approach for designer use of formatted data to achieve lower fabrication costs: both CDE and CED.	DIRECTION
• Qualitative cost guidance while developing low cost design configuration alternatives for parts and assemblies: CDE.	COMPARISON
• The capability to perform trade-offs to estimate actual fabrication man-hours or costs: CED.	COST

3.2 The Discrete Part

Detailed or discrete parts, ready for assembly in the airframe or electronic system, are analyzed to determine the cost driving manufacturing man-hour data for presentation to the designer. These are base parts, e.g., a sheet metal angle with no complexities - plus designer influenced cost elements (DICE). Examples of DICE for the sheet metal angle are heat treatment, cutouts, joggles, and special tolerances. The DICE are, therefore, added to a simple, base part to provide a discrete part that functions in an airframe or electronic system. The building block approach is illustrated in Figure 6. Typical base and discrete parts are shown in Figures 7 and 8.



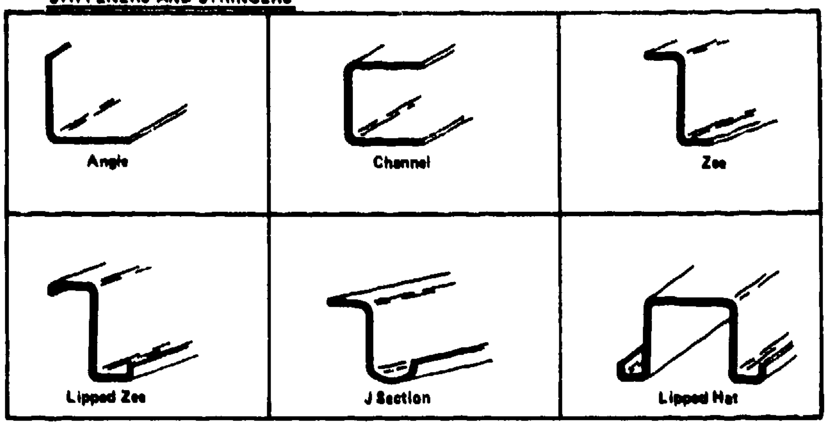
UTILIZATION OF SHEET-METAL AEROSPACE DISCRETE PART AND MECHANICALLY FASTENED ASSEMBLIES DEMONSTRATION SECTIONS

FIGURE 6. INSTRUCTIONS FOR USING MC/DG WORKSHEET

Sheet Metal Aerospace Base Parts

1. ALUMINUM

STIFFENERS AND STRINGERS



Part Lengths

24" to 144"

Manufacturing Methods

Straight Parts	Contoured Parts
• Brake Form	• Brake/Buffalo Roll
• Rubber Press	• Brake/Stretch
	• Rubber Press

FIGURE 7. EXAMPLE OF "BASE" PART

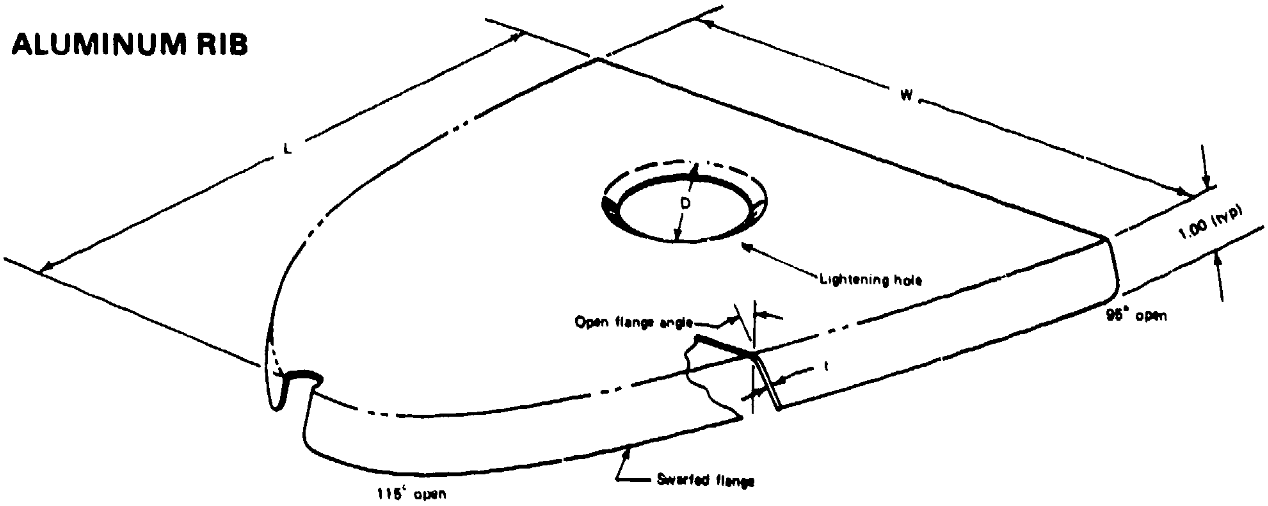


FIGURE 8. EXAMPLE OF DISCRETE PART

3.3 Ground Rules

In developing MC/DG data, ground rules were important to promote understanding and to ensure consistency, uniformity and accuracy in generating and integrating data into formats. The ground rules are in two categories, general and detailed, which for sheet metal parts are:

3.3.1 General Ground Rules

The general ground rules are categorized for:

(a) Sheet-Metal Discrete Parts

(b) Materials

(c) Manufacturing Methods

(d) Facilities

(e) Data Generation - Recurring Costs

(f) Data Generation - Non-Recurring Costs

(g) Support Function Modifiers.

3.3.2 Detailed Ground Rules

The detailed ground rules are categorized for:

(a) Materials

(b) Gages (Thicknesses)

(c) Tolerances

(d) Discrete Parts

(e) Manufacturing Methods

(f) Facilities

(g) Contract Tooling.

3.4 Format Development Criteria

Prior to developing data and with Air Force approval, Battelle Memorial Institute conducted a survey in many large aerospace companies, receiving 84 responses. From survey results and discussions at workshops held in 1976 at the initial industry briefing at Battelle Memorial Institute, the following criteria were identified to ensure that the cost driver effect (CDE) and cost estimating data (CED) formats would achieve designer usage:

1. EMPHASIZE COST DRIVERS

The MC/DG will emphasize sensitive factors, which, by minor variation in selection, can cause major increases or decreases in manufacturing cost. The degree to which the selection of materials, manufacturing, and fabrication processes impact manufacturing cost must be depicted in formats and data in a way that makes the designer readily aware of those elements of design (cost drivers) that pose manufacturing cost hazards.

2. BE SIMPLE TO USE

Guidance to designers will be presented in CDE and CED formats that minimize the arithmetical calculations required to determine the cost comparisons of design/manufacturing alternatives. The cost impact formats and graphics will provide more direct read-out of man-hours through maximum use of simple curves and tables.

3. USE DESIGNER LANGUAGE

The primary purpose of the MC/DG is to display manufacturing process capabilities and costs in such a manner that designers can select the most economical manufacturing approach. The formats must be developed through a close working relationship with design personnel at all the team member companies and through constructive recommendations submitted during the development of the MC/DG. The charts and terminology included with the formats must be common to the engineering community and be of the types that are recognized and employed by the designers in their daily engineering tasks.

4. INSTILL CONFIDENCE

The designer must have a high degree of confidence in the CDE and CED formats and manufacturing man-hour data if the MC/DG is to provide a useful working tool. The formats developed will be related to practical and meaningful cost trade-offs that illustrate airframe design decisions made every day by designers. The formats must clearly provide an MC/DG for making trade-off decisions between manufacturing technologies with both comparative and quantitative cost data. It is recognized that the degree of accuracy of manufacturing man-hour data integrated into the formats will be a significant factor in determining the confidence in and degree of utilization of the MC/DG in industry.

5. BE ECONOMICAL

A high priority item in the development of the MC/DG is to reduce costs for acquiring and maintaining the data and formats to a minimum.

6. BE ACCESSIBLE

The MC/DG must be physically and readily available at all designer locations. This will be handled differently within each company, but along similar lines. Copies of the MC/DG can be issued to individual designers or small engineering groups. The wider the distribution of the MC/DG to individual users, the more extensive the expected use. The breadth and distribution will be weighed between the ease of access by individual designers and the cost of distribution. Computerization will greatly enhance the accessibility.

7. BE MAINTAINABLE

The formats must be developed to facilitate maintenance of the MC/DG. In today's highly fluid technical and economic environment, the useful life of the MC/DG will depend on the flexibility of the formats to accept revised or new data. One approach is through computer preparation of individual pages of loose-leaf-type volumes. The data would be stored in the central data bank and, for user accessibility, transmitted via telephone connections to remote terminals at each company for printout and multiple distribution.

3.5 Manufacturing Cost Drivers

To develop a structured model of the MC/DG, i.e., with a section-by-section layout of the MC/DG for airframes, it was necessary to identify the cost drivers for each conventional and emerging manufacturing technology included in the contents of the MC/DG shown in Table 3.

Examples of cost drivers in typical fabrication processes are:

Forging

- Forging process
- Material
- Quality requirements
  - Tolerances
  - Metallurgical properties
  - NDI/NDE
- Quantity, lead time, and lot size
- Part complexity
- Size

Casting

- Casting process
- Material
- Quality requirements
  - Tolerances and surface texture
  - Metallurgical properties
  - NDI/NDE
- Quantity, lead time, and lot size
- Part complexity
- Size
- Machining requirements

Mechanical Fastening

- Accessibility
- Jigging requirements
- Sequencing requirements
- Materials joined
- Sealing
- Quantity
- Stack-up of parts
- Number of parts
- Number and types of fasteners
  - Hand rivets
  - Drivematic rivets
  - Threaded fasteners
- Tolerances
- Assembly size

Surface Treatment

- Surface preparation
- Size
- Complexity
- Energy requirements
- Quantity
- Materials
- Tolerances

Advanced Composite Fabrication

- Fiber types
- Fiber mix (hybrids)
- Resin systems
- Part type and function
- Part size
- Number of plies
- Manual lamination
- Curing method
- Facility requirements
- Tooling concepts
- Test, inspection, and evaluation requirements

Sheet Metal Forming

- Material type (formability)
- Part complexity
- Size
- Tolerances
- Quantity
- Heat-treatment
- Inspection

Machining (metals)

- Material type (hardness)
- Initial form (plate, forging, etc.)
- Part complexity
- Corner radius/end-mill diameter
- Pocket volume
- Slot depth
- Web height/thickness
- Unsupported web
- Number of splines or serrations
- Tolerances
- Surface finish

Based on these cost drivers, data requirements were specified for subsequent development of the designer-oriented formats to present cost and man-hour data. The MC/DG section Selection Aid is shown in Figure 9. Examples of these formats are shown in Figures 10 to 16.

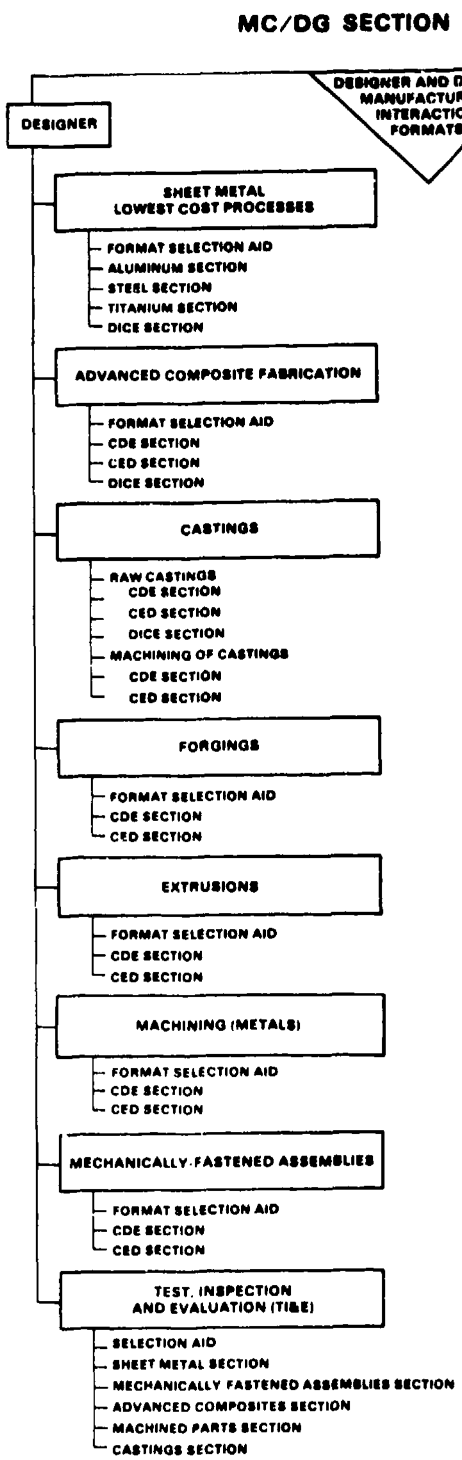


FIGURE 9. MC/DG SECTION SELECTION AID FOR AIRFRAME VOLUMES

GUIDE TO DESIGNER INFLUENCED COST ELEMENTS (DICE)

MATERIAL	DESIGNER INFLUENCED COST ELEMENTS / BASE PART MANUFACTURING METHOD	STANDARD JOGGLE	FLANGED HOLES	BEADS	HEAT TREATMENT	SPECIAL FINISH	SPECIAL TOLERANCE	LINEAL TRIM	END TRIM	CUTOUTS W/O FLANGES
ALUMINUM	BRAKE FORM	L	L	X	H	L	H	L	L	L
	BRAKE/BUFFALO ROLL	L	L	X	H	L	H	A	L	A
	BRAKE STRETCH	L	L	X	H	L	N	A	A	A
	DIE FORM	N	N	N	N	L	N	L	L	L
	DROP HAMMER	N	N	N	L	L	H	L	X	A
	FARNHAM ROLL	X	L	X	L	L	H	L	X	A
	ROUTED FLAT SHEET	X	L	X	L	L	H	L	X	L
	RUBBER PRESS	N	N	H	N	L	A	L	L	L
	STRETCH FORM	X	L	A	N	L	N	A	X	A
	YODER ROLL	L	L	X	H	L	H	A	A	A
	YODER STRETCH	L	L	H	N	L	N	A	L	A
TITANIUM	BRAKE FORM R.T.	A	L	X	X	L	H	H	H	L
	R.T. BRAKE/HOT STRETCH*	A	L	X	X	L	L	H	H	H
	CREEP FORM*	X	L	X	X	L	L	H	H	H
	FARNHAM ROLL	X	L	X	X	L	H	H	H	H
	HOT PRESS*	N	L	N	X	L	L	N	N	L
	PREFORM/HOT SIZE*	N	L	N	X	L	L	N	N	L
STEEL	BRAKE AND BUFFALO ROLL	A	L	X	N	L	H	H	A	L
	BRAKE FORM R.T.	A	L	X	N	L	H	L	L	L
	BRAKE/R.T. STRETCH	A	L	X	N	L	A	H	L	A
	FARNHAM ROLL	X	L	X	N	L	H	H	L	A
	RUBBER PRESS	N	N	N	N	L	A	L	L	L
	STRETCH FORM	X	L	X	N	L	A	H	A	L

LEGEND

RATING	
X	NOT APPLICABLE
N	NO ADDITIONAL COST INCL. IN BASE PART COST
L	LOW ADDITIONAL COST
A	AVERAGE ADDITIONAL COST
H	HIGH ADDITIONAL COST

Percentage Cost Ranges For Above

L	Up to 10%
A	10–30%
H	Above 30%

*Denotes one or more elevated temperature processing steps.

FIGURE 10. EXAMPLE OF DICE FORMAT FOR SHEET METAL PARTS

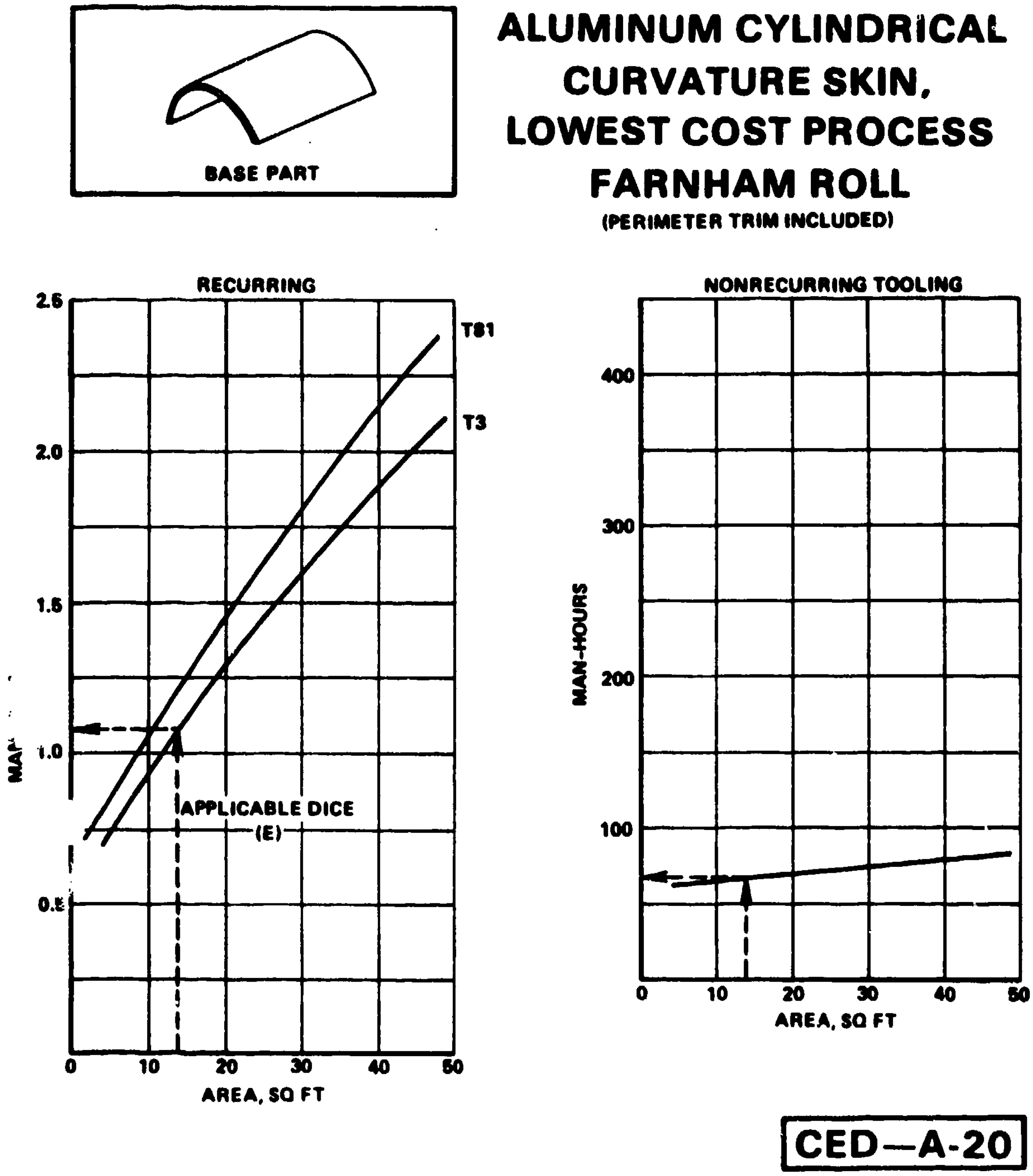


FIGURE 11. EXAMPLE OF CED FORMAT FOR ALUMINUM SKIN

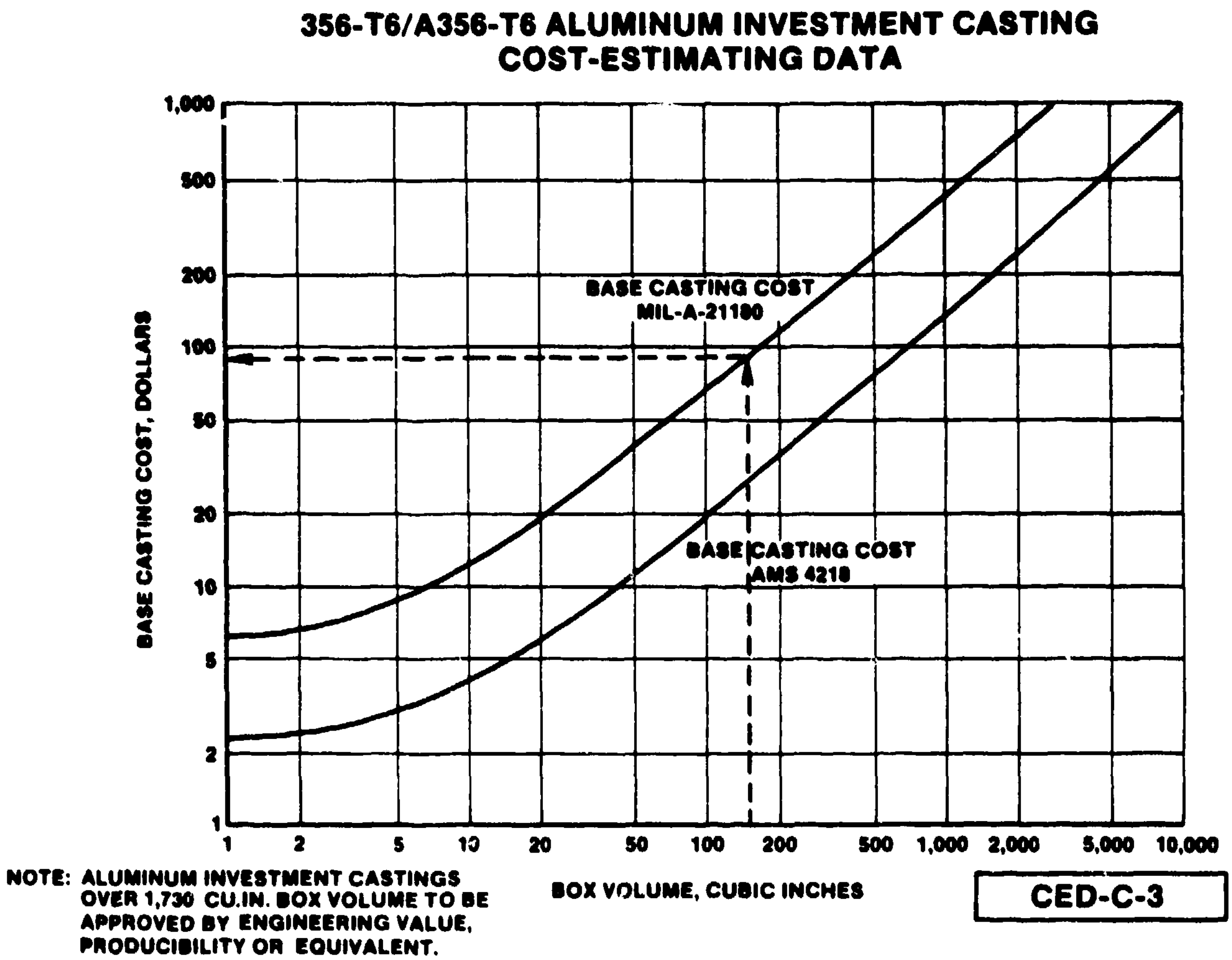


FIGURE 12. EXAMPLE OF CED FORMAT FOR ALUMINUM INVESTMENT CASTINGS

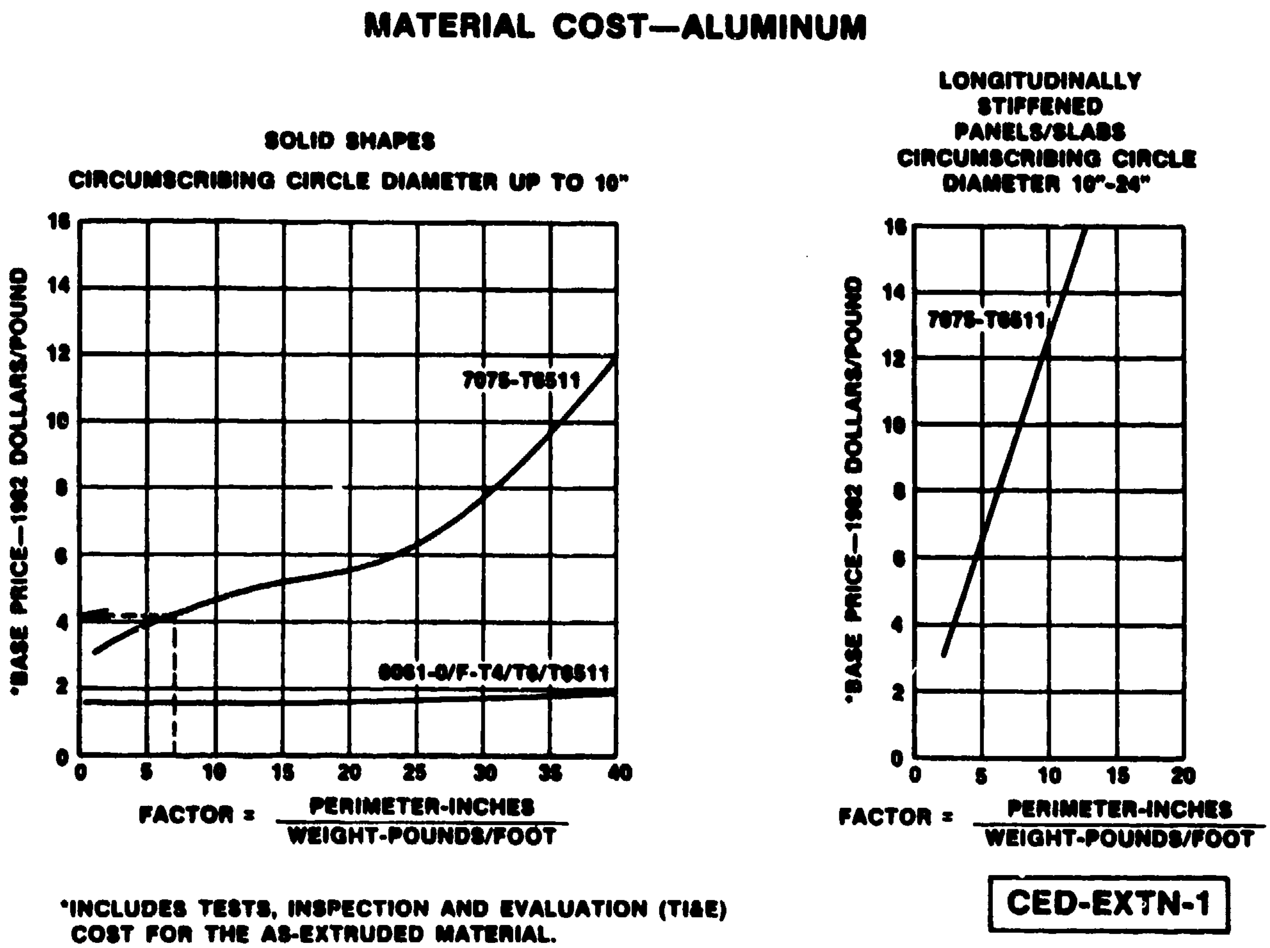
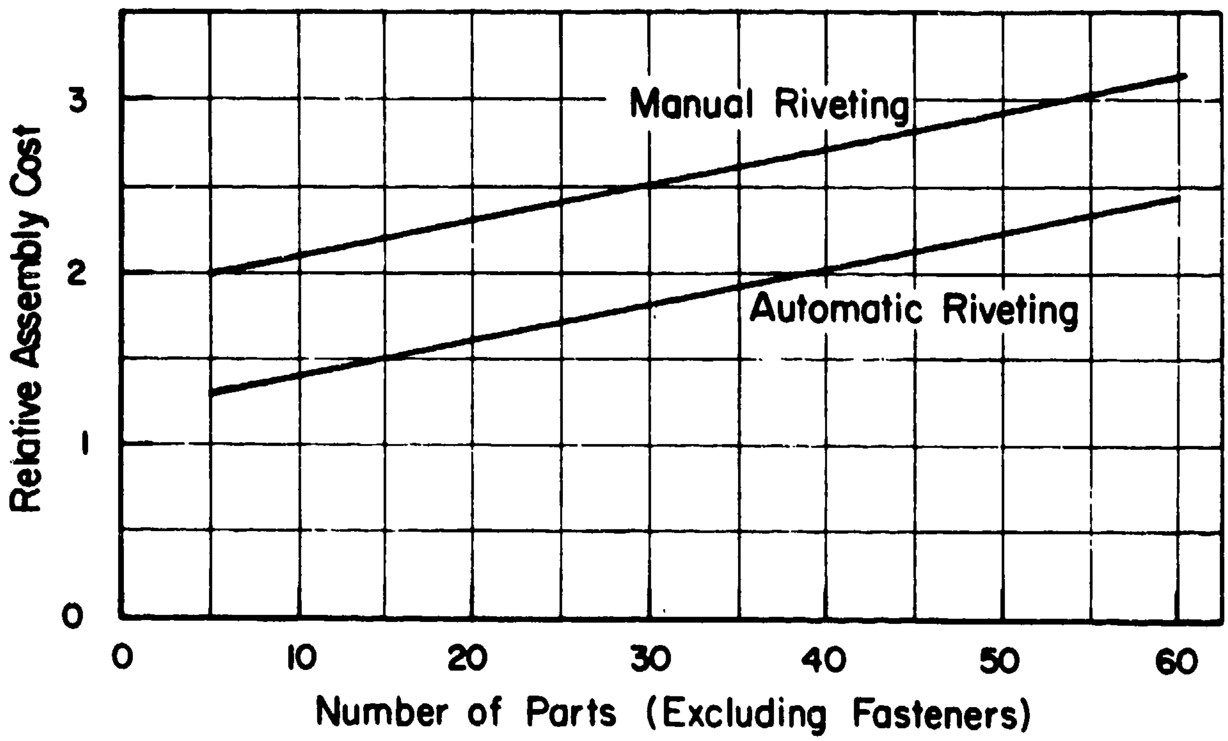


FIGURE 13. EXAMPLE OF CED FORMAT FOR MATERIAL COST OF ALUMINUM EXTRUSION

EFFECT OF PART COUNT AND FASTENING METHOD



CDE-MFA-II

FIGURE 14. EXAMPLE OF CDE FORMAT FOR METALLIC ASSEMBLIES

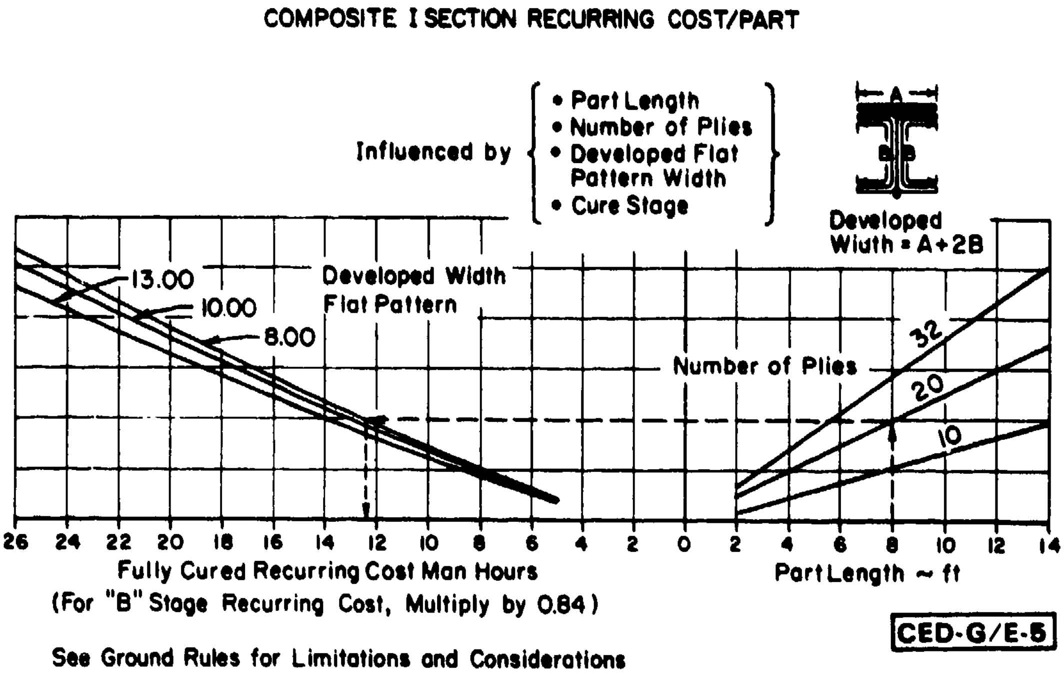


FIGURE 15. EXAMPLE OF CED FORMAT FOR CARBON/EPOXY LINEAL SHAPE

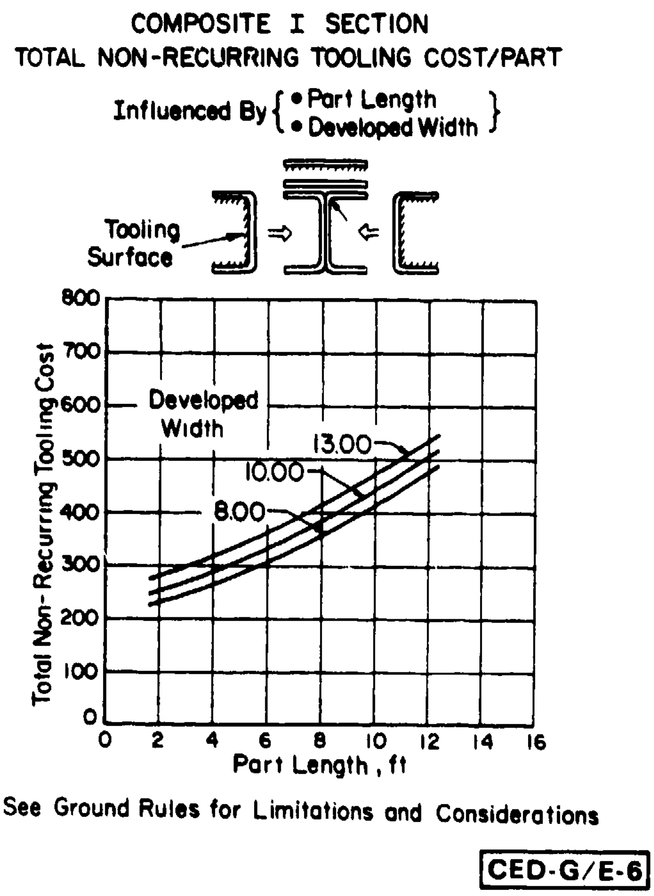


FIGURE 16. EXAMPLE OF CED FORMAT FOR NON-RECURRING COST OF CARBON/EPOXY LINEAL SHAPE

SECTION 4.0
MANUFACTURING TECHNOLOGY COST RESULTS

4.1 Data

The data requirements and designer-oriented formats identifying manufacturing cost drivers, both qualitatively and in man-hours, were prepared under Contract No. F33615-75-C-5194, enabling development of a model of the MC/DG, a section-by-section lay-out of all formats, and an implementation plan. This program is reported in Reference 4. The MC/DG sections subsequently developed enable designers to conduct manufacturing cost trade-off studies, for example, between sheet metal assemblies, such as sheet metal panels with built-up stringer sections, and extrusion stiffened panels. Furthermore, they make it possible to compare the manufacturing cost of castings and forgings with built-up sheet metal assemblies. The completed programs required development of the following MC/DG sections, of which several have been demonstrated in the airframe design process:

- Castings
- Composites (limited, four-month program)
- Extrusions
- Forgings
- Machining (metals)
- Mechanically-fastened assemblies
- Sheet metal discrete parts
- Test, inspection, and evaluation (TI&E).

4.2 Formats

To develop designer-oriented formats, it was necessary to identify cost drivers for each manufacturing technology in the MC/DGs (see Section 3.5). Data calculated by the MC/DG team, and presented in the formats, respond to aerospace industry requirements. The guides have formats for each manufacturing process corresponding to the cost drivers as listed in Section 3.5.

Because designers are concerned with achieving the lowest cost, the guides present primarily the man-hours for the lowest-cost processes to manufacture a specific structural element. However, they also offer, in the case of sheet metal, information on multiple-part configurations that can be produced with, a single manufacturing method and on multiple manufacturing methods that can produce a specific part. It is important to identify facilities providing the lowest-cost approach, so if they are already committed for other programs, management can decide either to accept a cost penalty or to procure parts from an outside source.

SECTION 5.0
DEMONSTRATIONS BY DESIGNERS

To evaluate the capabilities of the MC/DG formats, designers at three participating companies were asked to use the MC/DG in demonstration studies. These trade-off studies followed the steps described in the following discussion.

5.1 Trade-off Study for a Part

The steps in a typical trade-off study using an example of sand casting versus investment castings, are:

1. Initiate cost work sheet for sand casting
2. Determine base casting cost
3. Select designer influenced cost elements (DICE)
4. Determine lot quantity factor and test, inspection, and evaluation (TI&E) costs
5. Complete machining cost work sheet
6. Determine machining costs
7. Initiate cost work sheet for investment casting
8. Select DICE
9. Complete machining cost work sheet
10. Prepare summary of trade-off, i.e., machined sand casting versus machined investment casting, indicating cost of each casting, and compare with value of weight saved for system.

5.2 Trade-off Study for an Assembly

The intent of the MC/DG is to point the assembly designer to the lowest cost structural candidate that meets design objectives, which can encompass:

- Strength and stiffness
- Minimum weight
- Satisfactory performance at elevated temperature
- Fatigue strength
- Minimum maintenance
- Crashworthiness
- Corrosion resistance
- Damage tolerance
- Ease of repair.

To conduct manufacturing cost trade-off studies for a fuselage panel assembly, the designer:

(a) Develops concepts, which require selecting or determining the:

- material
- skin panel sizing
- frame shape
- number of frames required
- joining method, e.g., bonding versus rivets
- candidate manufacturing methods for each discrete part in the assembly

(b) Determines manufacturing cost for each panel configuration

(c) Determines assembly costs for each configuration

(d) Determines TI&E costs

(e) Determines total manufacturing costs, which include materials and tooling

(f) Determines weight of each panel assembly

(g) Presents manufacturing man-hours or costs and structural weight in summary tables and, when appropriate, on design charts that show structural weight versus manufacturing cost.

5.3 Fuselage Shear-Panel Trade-off Studies

Designers were required to use the data and formats for sheet-metal and composites in studies on actual shear panels for typical fuselages. The objectives of this requirement were to:

1. Demonstrate use of MC/DG in an industry environment for designing a typical airframe structure
2. Determine if the manufacturing cost (man-hour) formats providing CDE and CED information meet the format design criteria established
3. Determine if the CDE and CED formats provide the accuracy required by designers to conduct realistic comparisons

Designs for three different fuselage panels were studied in:

- Aluminum Alloy - by General Dynamics Corporation, Fort Worth Division
- Titanium Alloy - by Lockheed-California Company

- Carbon/Epoxy - by Rockwell International,
  North American Aircraft Division

The trade-off studies were reviewed by:

- Boeing Commercial Airplane Company
- Northrop Corporation, Aircraft Group.

The conclusions from the three trade-off studies were:

- The studies successfully demonstrated use of MC/DG
- Designers were able to perform manufacturing cost trade-offs
- The MC/DG formats were easy to interpolate.

The interaction between design and manufacturing and the building-block approach when using the MC/DG is illustrated in Figure 17. The MC/DG Cost Worksheet to summarize airframe part or assembly cost and/or total program cost is shown in Table 5, with the instructions in Table 6.

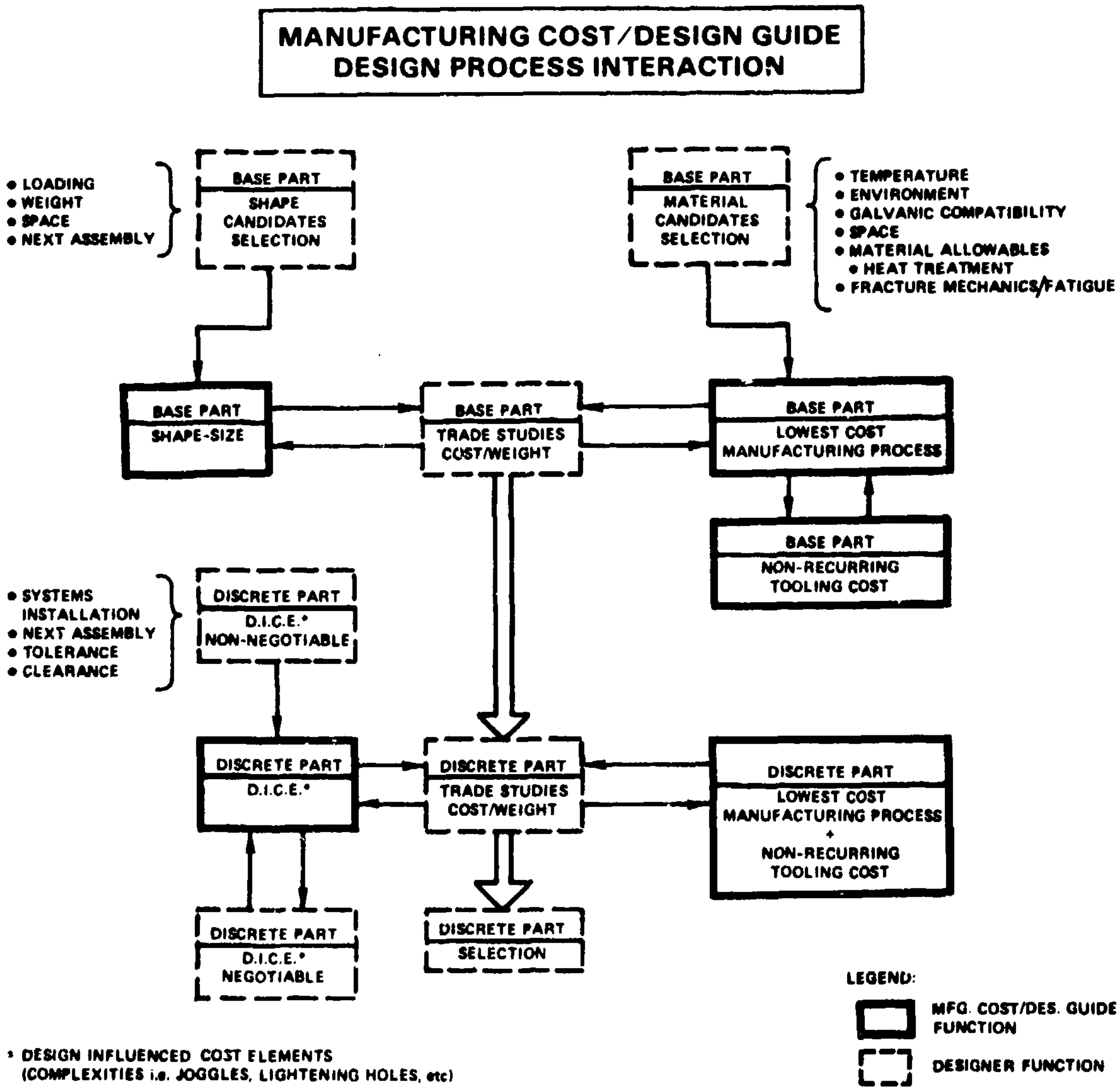


FIGURE 17. "MANUFACTURING COST/DESIGN GUIDE" DESIGN PROCESS INTERACTION

TABLE 6. INSTRUCTIONS FOR USING MC/DG WORKSHEET

Worksheet Column	Input	Procedure
	Part no.	Enter identification, if available.
	Description	Enter brief description, e.g., stiffener, Z & J sections
1	Manufacturing labor	Enter man-hours per part at 200 units determined from CED format.
2	Learning curve (LC) factor	Enter LC factor based upon learning curve percentage and design quantity. Factor provided by user company.
3	TI&E labor	From MC/DG, enter RC for TI&E (man-hours).
4	Labor rate	Enter current manufacturing labor rate, including direct labor fringe benefits and overhead charges.
5	Labor recurring costs (RC)	Enter the product of Column 1 times Column 2 plus Column 3 times Column 4.
6	Material cost	Based upon furnished data in company utilizing MC/DG enter material cost per part in dollars.
7	Recurring cost (RC) per part	Total of columns 5 and 6.
8	Parts per aircraft	Enter number of identical parts per aerospace system.
9	Design quantity	Enter number of aerospace systems in buy considered.
10	Program recurring cost (RC)	Enter the product of Column 7 times Column 8 times Column 9.
11	Nonrecurring tooling cost (NRTC) for part/assembly	From MC/DG enter NRTC in man-hours.
12	NRTC for TI&E	From MC/DG, enter NRTC for TI&E in man-hours.
13	Labor rate	See Column 3.
14	Program nonrecurring tooling costs (NRTC)	Enter the product of Column 13 times the total of Column 11 and 12.
15	Program cost	Enter the sum of Column 10 and Column 14.
16	Design quantity	See Column 9.
17	Cost per aircraft	Enter the quotient of Column 15 divided by Column 16.

SECTION 6.0
APPLICATIONS BY INDUSTRY

The data and formats developed have been distributed to industry in a series of Air Force reports listed at the conclusion of this summary. In the technology transfer volume, approximately 150 organizations cite 240 applications of the MC/DG. The following summary of potential uses of the MC/DG indicates the broad application of the data developed:

- As a working reference for evaluating the impact of engineering changes at various phases of system development
- For decisions on process alternatives based on costs of process routing and assembly techniques
- For use in various manufacturing-engineering operations to meet producibility requirements and to reduce cost
- As an authoritative standard and reference for cost and design information and for guidance in component design and fabrication
- As an aid in understanding cost implications of new manufacturing processes
- For estimating costs of group technology part families
- To guide planning of upgraded, computer-integrated manufacturing facilities within a specific capitalization program
- To conduct value analysis of manufacturing methods
- As a baseline for CAD/CAM implementation, construction cost trade-offs, and component ranking
- To familiarize the organization with the character of interaction between design and manufacturing.

The MC/DG will evolve as an important tool to accelerate technology transfer of the results of Air Force materials and manufacturing technology programs because it has the capability to:

- Accelerate utilization of R&D results by highlighting cost advantages
- Permit designers to perform trade-off studies in developing cost/weight effective designs for advanced airframe structures
- Provide experienced design engineers in preliminary design with data that will influence advanced design approaches
- Provide designers with manufacturing technology design trends
- Provide an interface between MC/DG emerging technologies and Air Force advanced manufacturing technology programs

SECTION 7.0
COST SAVINGS

The MC/DG data have been used successfully on many ongoing projects in industry resulting in cost savings, not only on hardware, but also in the design process. Examples are:

- On a composite door concept for the MX missile, the MC/DG allowed easy selection of a cost-effective, lightweight design. Designers were able to evaluate 10 concepts in just 8 hours, a process that would normally have taken 40 hours plus an additional 40 hours turnaround time involving the cost estimating department.
- A young engineering graduate, using the MC/DG, conducted a design trade-off study for aluminum fuselage shear panels on the F-16 aircraft. Of significance, the graduate conducted the trade-off easily and in much less time than for normal procedures involving cost estimating departments and coordination with seasoned design engineers. Feedback from industry indicates applying the MC/DG to composite, titanium, and aluminum panels, requires only four calculations for each concept. Conventional cost estimating methods require 20 to 40 calculations for similar cost determining activities. Inexperienced designers are seldom able to conduct such trade-off studies.
- MC/DG use led to substantial cost savings for the prime contractor on procurement of B-1B aircraft castings and forgings. The MC/DG provided cost driver guidance and improved interaction with the vendor.

As an example of the cost savings that may be realized, use of the MC/DG can reduce airframe acquisition costs by 2 to 5 percent. Thus, on a supersonic attack/fighter costing $14M, where the estimated airframe cost is 30 percent, the estimated program savings would be:

Number of Aircraft:	1	100	300	500
2 percent reduction:	$84,000	$8.4M	$25.2M	$42M
Equivalent airframes:		2	6	10
5 percent reduction:	$210,000	$21M	$63M	$105M
Equivalent airframes:		5	15	25

As mentioned earlier, the magnitude of cost savings will be significantly increased if the MC/DG is applied as early as possible in the design process. For this reason, the conceptual design phase is frequently referred to as the "window of opportunity"; it is here that the leverage exists to reduce cost.

Experienced designers in industry were requested to estimate the cost-savings impact of utilizing the ICAM "Manufacturing Cost/Design Guide" (MC/DG) through all phases of electronic systems development:

- Conceptual design phase
- Engineering design phase
- Prototype phase
- Preproduction phase
- Production phase.

The estimated payoffs from using the MC/DG on an inertial navigation system were:

- Purchase 600 systems at $60,000 each = $36,000,000 program
- Engineering design and development program, typically 2-year effort costing $2,000,000
- MC/DG increases design activity by 10 percent, i.e., $200,000 but is more efficient
- Use of ICAM MC/DG predicted to reduce material and labor cost of each system by 10 percent to $54,000
- Cost of total program now $32,400,000
- Savings estimated to be $3,400,000
- At manufacturing level, savings are greater (percentage).

The cost of avionics in aerospace systems is significant. For example, the labor and material costs for avionics in an advanced fighter can represent from 30 to 35 percent of the aircraft cost. An "MC/DG for Electronics" was, therefore, developed for use at the conceptual design phase, enabling new technology, number of assemblies, commonality, digital design, and part count to be analyzed. Using the formats during the detail design phase, designers can conduct trade-off studies on mechanization, processes, insertion, and soldering. In the effort to achieve affordable performance, the cost of meeting various specifications and, hence, reliability levels, is indicated; for example, for transistors, diodes, rectifiers, and integrated circuits.

SECTION 8.0
FUTURE REQUIREMENTS

8.1 Computerization

Computerization of the cost data and formats obviously represents a very important step in creating a tool that quickly gives the design engineer manufacturing costs associated with various design solutions. A sister program was therefore funded by the Computer Integrated Manufacturing Branch, Materials Laboratory, Air Force Wright Aeronautical Laboratories (AFWAL), to develop an automated system--the Manufacturing Cost Design System (MCDS). The prime contractor for the MCDS was Grumman Aerospace Corporation. This company was supported by Rockwell International, Northrop, Vought, Bell Helicopter, Control Data, and SofTech, Inc.

Besides using the MCDS for trade-off studies, designers will also be able to use the computerized version to:

- Determine cost impacts of
  - Material price fluctuations
  - Learning curve base, e.g., aircraft quantity ordered
  - Lot sizes
  - Labor rate increases
- Retrieve earlier design trade-off data in a readily usable and recognized form
- Ext polate and interpolate dimensional data for part manufacture and assembly.

Without the computer, designers find evaluation of critical information of this type to be time-consuming, intricate, and bothersome.

8.2 Additional Data and Formats

To complete the MC/DG, it is necessary to provide manufacturing man-hour or, cost data, and also designer-oriented formats, for a number of emerging techn ies, which include diffusion-bonding, superplastic forming and comb ations of these), adhesive-bonding, and weld-bonding. Manufacturing cost/structural performance trade-off studies are needed to compare emerging and conventional airframe designs. Furthermore, the MC/DG functional sections for composites and assembly developed to date represent the results of 4-month programs and, therefore, do not provide adequat scope for extensive use by airframe designers. The sections on composites and assembly need considerable expansion. The Computer Integrated Manufacturing Branch (AFWAL/MLTC), Manufacturing Technology Division, is considering a program to enable the additional sections indicated in Table 3 to be developed.

SECTION 9.0
CONCLUSIONS

Analysis of MC/DG development and application leads to the following conclusions:

- The viability and practicability of the MC/DG methodology base is established
- Designers can quickly retrieve required data
- Designer use of cost data involves only simple calculations
- The guide is for designer use; it is not a cost-estimating manual
- The MC/DG is an important tool for designers in performing trade-off studies and controlling costs
- The MC/DG is sensitive to configuration variations
- Use of the MC/DG reduces time for screening candidate designs; thus improving schedule compliance
- The MC/DG has been fully demonstrated as an effective design/manufacturing cost trade-off tool
- Cost/weight and cost/reliability charts are of particular merit, demonstrating cost-effectiveness of designs
- Use of the computer will expand and increase the number of trade-offs that can be performed by both preliminary and production designers
- Cost-savings are cumulative for all programs; Army, Navy and Air Force
- The MC/DG is a much needed tool for non-defense industries in the United States competing with foreign countries
- A properly maintained and updated MC/DG reduces the possibility of manufacturing man-hour data becoming obsolete.

SECTION 10.0
REFERENCE DOCUMENTS

10.1 Applicable Documents

Item	Description
1	Summary of Air Force/Industry Manufacturing Cost Reduction Study, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report No. AFML-TM-LT-73-1, January 1973.
2	Summary Report on the Low Cost Manufacturing/Design Seminar, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report No. AFML-TM-LT-74-3, 15 December 1973.
3	Aerospace Cost Savings - Implications for NASA and the Industry, National Materials Advisory Board, National Academy of Sciences, Report No. NMAB-328, 1975.
4	Noton, B.R., et al, "Manufacturing Cost/Design Guide", Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report No. AFML-TR76-227, December 1976.
5	"Manual for Panel Chairmen and Working Groups", Department of Defense/Industry Metal Chip Removal Conference, p. 16, 8-10 February 1977, Daytona Beach, Florida.
6	Noton, B.R., Claydon, C.R., Larson, M., "ICAM Manufacturing Cost/Design Guide", Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Technical Report AFWAL-TR-80-4115, September 1977 - July 1979: a. Volume I: Demonstration Sections b. Volume II: Appendices to Demonstration Sections c. Volume III: Computerization.
7	Integrated Computer Aided Manufacturing (ICAM) "Manufacturing Cost/Design Guide" (MC/DG) Interim Technical Reports for Period: a. 28 September 1979 - 29 February 1980, ITR450260001U b. 28 September 1979 - 16 May 1980, ITR450260002U c. 17 May 1980 - 17 August 1980, ITR450260003U d. 18 August 1980 - 31 October 1980, ITR450260004U e. 1 November 1980 - 31 January 1981, ITR450260005U f. 2 February 1981 - 30 April 1981, ITR450260006U

g. 4 May 1981 - 31 July 1981, ITR450260007U
h. 3 August 1981 - 30 October 1981, ITR450260008U
i. 2 November 1981 - 29 January 1982, ITR450260009U
j. 1 February 1982 - 30 April 1982, ITR4502600010U
k. 1 September 1983 - 30 November 1983, ITR450260011U
l. 1 December 1983 - 29 February 1984, ITR450260012U
m. 1 June 1984 - 31 August 1984, ITR450260013U

8 MC/DG User's Manual for Airframes, AFWAL-TR-83-4033 (Volumes I, II, III & V).

9 MC/DG User's Manual for Electronics, AFWAL-TR-83-4033 (Volume IV).

10 Technology Transfer Summary, TTD450260000 (Volume VII).

DOCUMENT REQUEST ORDER FORM

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Battelle's Columbus Laboratories
505 King Avenue, Columbus, Ohio 43201

VOLUME NUMBER AND MANAGEMENT NUMBER	TITLE OF DOCUMENT	INDICATE (✓) DOCUMENT REQUESTED
AFWAL-TR-80-4115 (VOLUMES I, II & III)	ICAM "MANUFACTURING COST/DESIGN GUIDE" (DEMONSTRATION SECTIONS AND COMPUTERIZATION)	
AFWAL-TR-83-4033 (VOLUMES I, II & III)	MC/DG USER'S MANUAL FOR AIRFRAMES	
AFWAL-TR-83-4033 (VOLUME IV)	MC/DG USER'S MANUAL FOR ELECTRONICS	
FTR450260000 (Volume V)	PROJECT SUMMARY	
TTD450260000 (Volume VI)	TECHNOLOGY TRANSFER SUMMARY	

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